CHAPTER 3

EVALUATION, DESIGN, AND PROCESSING OF BACKFILL MATERIALS

3-1. General. The evaluation, design, and proper processing of backfill materials are extremely important phases of the preconstruction operations. The purpose of the evaluation phase is to determine the engineering characteristics of potential backfill materials. The design phase must take into account the engineering characteristics required of the backfill and specify materials that, when compacted properly, will have these characteristics. Proper processing of the backfill material will ensure that desirable engineering characteristics will be obtained as the material is placed.

3-2. Evaluation of backfill materials. Evaluation of backfill materials consists of exploration, sampling, and laboratory testing to determine the engineering characteristics of potential backfill materials. Detailed instructions for exploration, sampling, laboratory testing, and foundation design are presented in TM 5-818-1/AFM 88-3, Chapter 7. However, to emphasize the need for an adequate investigation, some aspects of planning and investigation that should be considered are discussed in the following paragraphs.

a. Field exploration and sampling. Field exploration and sampling are extremely important to the design of foundations, selection of backfill, and planning for construction. A great amount of material will be available from required excavations, and the investigation for foundation conditions should include the sampling and evaluation of these materials for possible use as backfill. Where an adequate volume of suitable backfill cannot be obtained from the construction excavation, the exploration and sampling program must be expanded to find other sources of suitable material whether from nearby borrow areas or commercial sources.

(1) The purpose of the investigation is to delineate critical conditions and provide detailed information on the subsurface deposits so that proper design and construction, including backfilling operations, can be accomplished with minimum difficulty. Thus careful planning is required prior to the field exploration and sampling phase of the investigation. Available geologic and soil data should be studied, and if possible, preliminary borings should be made. Once a site has been tentatively selected, orientation of the structure to the site should be established. The engineer who plans the detailed field exploration program must have knowledge of the structure, i.e., its configuration and foundation requirements for design loads and settlement tolerances. The planning engineer should also know the type and quantity of backfill required. The importance of employing qualified field exploration personnel cannot be overemphasized. The exploration crews should be supervised in the field by a soils engineer or geologist familiar with the foundation and backfill requirements so that changes can be made in the exploration program where necessary to provide adequate information on subsurface conditions.

(2) The field engineer should also know the location of significant features of the structure so that sampling can be concentrated at these locations. In addition, he should have an understanding of the engineering characteristics of subsurface soil and rock deposits that are important to the design of the structure and a general knowledge of the testing program so that the proper type and quantity of samples will be obtained for testing.

(3) From the samples, the subsurface deposits can be classified and boring logs prepared. The more continuous the sampling operation, the more accurate will be the boring logs. All borings should be logged with the description of the various strata encountered as discussed in TM 5-818-1/AFM 88-3, Chapter 7. Accurate logging and correct evaluation of all pertinent information are essential for a true concept of subsurface conditions.

(4) When the exploratory borings at the construction site have been completed, the samples and logs of borings should be examined to determine if the material to be excavated will be satisfactory and in sufficient quantity to meet backfill requirements. Every effort should be made to use the excavated materials; however, if the excavated materials are not satisfactory or are of insufficient quantity, additional exploration should be initiated to locate suitable borrow areas. If borrow areas are not available, convenient commercial sources of suitable material should be found. Backfill sources, whether excavation, borrow, or commercial, should contain several times the required volume of compacted backfill.

(5) Groundwater studies prior to construction of subsurface structures are of the utmost importance, since groundwater control is necessary to provide a dry excavation in which construction and backfilling

operations can be properly conducted. Data on groundwater conditions are also essential for forecasting construction dewatering requirements and stability problems. Groundwater studies must consist of investigations to determine: groundwater levels to include any seasonal variations and artesian conditions; the location of any water-bearing strata; and the permeability and flow characteristics of water-bearing strata. Methods for investigating groundwater conditions are described in TM 5-818-1/AFM 88-3, Chapter 7, and TM 5-818-5/NAVFAC P-418/AFM 88-5, Chapter 6.

b. Laboratory testing. The design of any foundation is dependent on the engineering characteristics of the supporting media, which may be soil or rock in either its natural state or as compacted backfill. The laboratory testing program will furnish the engineer information for planning, designing, and constructing subsurface structures. Laboratory testing programs usually follow a general pattern and to some extent can be standardized, but they should be adapted to particular problems and soil conditions. Special tests and research should be utilized when necessary to develop needed information. The testing program should be well planned with the engineering features of the structure and backfill in mind; testing should be concentrated on samples from areas where significant features will be located but should still present a complete picture of the soil and rock properties. The laboratory test procedures and equipment are described in TM 5-818-1/AFM 88-3, Chapter 7, EM 1110-2-1906, and MIL-STD-621.

(1) *Identification and classification of soils*. The Unified Soil Classification System used for classifying soils for military projects (MIL-STD-619 and TM 5-818-1/AFM 88-3, Chap. 7) is a means of identifying a soil and placing it in a category of distinctive engineering properties. Table 3-1 shows the properties of soil groups pertinent to backfill and foundations. Using these characteristics, the engineer can prepare preliminary designs based on classification and plan the laboratory testing program intelligently and economically.

(*a*) The Unified Soil Classification System classifies soils according to their grain-size distribution and plasticity characteristics and groups them with respect to their engineering behavior. With experience, the plasticity and gradation properties can be estimated using simple, expedient tests (see table 2-2 and 2-3 of TM 5-818-1/AFM 88-3, Chap. 7 or AFM 89-3, Chap. 2) and these estimates can be confirmed using simple laboratory tests. The principal laboratory tests performed for classification are grain-size analyses and Atterberg limits.

(*b*) The engineering properties in table 3-1 are based on "Standard Proctor" (CE 25) maximum density except that the California Bearing Ratio (CBR) and the subgrade modulus are based on CE 55 maximum density. This information can be used for initial design studies. However, for final design of important structures, laboratory tests are required to determine actual performance characteristics, such as CE 55 compaction properties, shear strength, permeability, compressibility, swelling characteristics, and frost susceptibility where applicable, under expected construction conditions.

(*c*) The Unified Soil Classification System is particularly useful in evaluating, by visual examination, the suitability of potential borrow materials for use as compacted backfill. Proficiency in visual classification can be developed through practice by comparing estimated soil properties with results of laboratory classification tests.

(2) Compaction testing. Compaction test procedures are described in detail in MIL-STD-621 and ASTM D 1557 (app. A). It is important that the designer and field inspection personnel understand the basic principles and fundamentals of soil compaction. The principles of soil compaction are discussed in appendix B of this manual.

(*a*) The purpose of the laboratory compaction tests are to determine the compaction characteristics of available backfill materials. Also, anticipated field density and water content can be approximated in laboratory-compacted samples in order that other engineering properties, such as shear strength, compressibility, consolidation, and swelling, can be studied. For most soils there is an optimum water content at which a maximum density is obtained with a particular compaction effort. A standard five-point compaction curve relating density and water content (fig. B-1, app. B) can be developed by the procedures outlined in MILSTD-621.

(*b*) The impact compaction test results normally constitute the basis on which field compaction control criteria are developed for inclusion in the specifications. However, for some cohesionless soils, higher densities can be obtained by the vibratory compaction method (commonly referred to as maximum relative density), described in appendix XII of EM 1110-21906. The required field compaction is generally specified as a percentage of laboratory maximum dry density and referred to as percent CE 55 maximum density. Water content is an important controlling factor in obtaining proper compaction. The required percentage of maximum dry density and the compaction water content should be selected on the basis of the engineering characteristics, such as compression moduli, settlement, and shear strength, desired in the compacted backfill. It should be noted that these characteristics could be adversely effected by subsequent increases in water content after placement. This situation could result from an increase in the groundwater level after construction.

(*c*) Density control of placed backfill in the field can be facilitated by the use of rapid compaction check tests (para 7-5c). A direct rapid test is the one-point impact compaction test. Rapid indirect tests, such as the Proctor needle penetration for cohesive soils or the tone resistance load for cohesionless soils, can also be used when correlations with CE 55 maximum density have been established.

(3) *Shear strength testing.* When backfill is to be placed behind structure walls or bulkheads or as foundation support for a structure, and when fills are to be placed with unrestrained slopes, shear tests should be performed on representative samples of the backfill materials compacted to expected field densities and water contents to estimate as-constructed shear strengths. The appropriate type of test required for the conditions to be analyzed is presented in TM 5-818-1/AFM 88-3, Chapter 7. Procedures for shear strength testing are described in EM 1110-2-1906.

Table 3-1. Typical Engineering Properties of Compacted Materials a

				Typical Value of Compression, Percent of Original Height		Typical Strength Characteristics						
Group Symbol	Soil Type	Range of Maximum Dry Unit Weight, pcf	Range of Optimum Water, Content Percent	At 2.5 ksf (20 psi)	At 7.2 ksf (50 psi)	Cohesion (As Compacted) psf	Cohesion (Saturated) psf	ϕ (Effective Stress Envelope) deg	Typical Coefficient of Permeability ft/min	Range of CBR Values	Range of Subgrade Modulus k lb/cu in.	Potential Frost Action[b]
GW	Well-graded clean gravels, gravel-sand mixtures	125-135	11-8	0.3	0.6	0	0	>38	5×10^{-2}	40-80	300-500	None to very slight
GP	Poorly graded clean gravels, gravel-sand mix	115-125	14-11	0.4	0.9	0	0	>37	10^{-1}	30-60	250-400	None to very slight
GM	Silty gravels, poorly graded gravel-sand-silt	120-135	12-8	0.5	1.1	--	--	>34	$>10^{-6}$	20-60	100-400	Slight to medium
GC	Clayey gravels, poorly graded gravel-sand-clay	115-130	14-9	0.7	1.6	--	--	>31	$>10^{-7}$	20-40	100-300	Slight to medium
SW	Well-graded clean sands, gravelly sands	110-130	16-9	0.6	1.2	0	0	38	$>10^{-3}$	20-40	200-300	None to slight
SP	Poorly graded clean sands, sand-gravel mix	100-120	21-12	0.8	1.4	0	0	37	$>10^{-3}$	10-40	200-300	None to slight
SM	Silty sands, poorly graded sand-silt mix	110-125	16-11	0.8	1.6	1050	420	34	5×10^{-5}	10-40	100-300	Slight to medium
SM-SC	Sand-silt clay mix with slightly plastic fines	110-130	15-11	0.8	1.4	1050	300	33	2×10^{-6}	--		
SC	Clayey sands, poorly graded sand-clay mix	105-125	19-11	1.1	2.2	1550	230	31	5×10^{-7}	5-20	100-300	Slight to high
ML	Inorganic silts and clayey silts	95-120	24-12	0.9	1.7	1400	190	32	10^{-5}	15 or less	100-200	Medium to very high
ML-CL	Mixture of inorganic silt and clay	100-120	22-12	1.0	2.2	1350	460	32	5×10^{-7}	--	100-200	
CL	Inorganic clays of low to medium plasticity	95-120	24-12	1.3	2.5	1800	270	28	10^{-7}	15 or less	50-200	Medium to high
OL	Organic silts and silt-clays, low plasticity	80-100	33-21	--	--	--	--	--	--	5 or less	50-100	Medium to high
MH	Inorganic clayey silts, elastic silts	75-95	40-24	2.0	3.8	1500	420	25	5×10^{-7}	10 or less	50-100	Medium to very high
CH	Inorganic clays of high plasticity	80-105	36-19	2.6	3.9	2150	230	19	10^{-7}	15 or less	50-150	Medium
OH	Organic clays and silty clays	75-100	45-21	--	--	--	--	--	--	5 or less	25-100	Medium

Notes:

1. All properties are for condition of "standard Proctor" maximum density, except values of k and CBR which are for CE55 maximum density.
2. Typical strength characteristics are for effective strength envelopes and are obtained from USER data.
3. Compression values are for vertical loading with complete lateral confinement.
4. (>) indicates that typical property is greater then the value shown. (-) indicates insufficient data available for an estimate.

[a] After DM-7.

[b] From TM 5-18-2/AP 88-6. Chapter 4.

(4) *Consolidation and swell testing*. The rate and magnitude of consolidation under a given load are influenced primarily by the density and type of soil and the conditions of saturation and drainage. Fine grained soils generally consolidate more and at a slower rate than coarse-grained soils. However, poorly graded, granular soils and granular soils composed of rounded particles will often consolidate significantly under load but usually at a relatively fast rate.

(*a*) The procedure for the consolidation test is outlined in EM 1110-2-1906. The information obtained in this test can be used in settlement analyses to determine the total settlement, the time rate of settlement, and the differential settlement under varying loading conditions. Consolidation characteristics are important considerations in selection of backfill materials. The results of consolidation tests performed on laboratory compacted specimens of backfill material can be used in determining the percent compaction to be required in the specifications.

(*b*) Swelling characteristics can be determined by a modified consolidation test procedure. The degree of swelling and swelling pressure should be determined on all backfill and foundation materials suspected of having swelling characteristics. This fact is particularly important when a considerable overburden load is removed by excavation or when the compacted backfill with swelling tendencies may become saturated upon removal of the dewatering system and subsequent rise of the groundwater level. The results of swelling tests can be used to determine the suitability of material as backfill. When it is necessary to use backfill materials that have a tendency to swell upon saturation because more suitable materials are unavailable, the placement water content and density that will minimize swelling can be determined from a series of tests. TM 5-818-1/AFM 88-3, Chapter 7, and FHWA-RD-79-51 (app. A) provide further information applicable to compacted backfills.

(5) *Permeability tests*. Permeability tests to determine the rate of flow of water through a material can be conducted in the laboratory by procedures described in EM 1110-2-1906. Permeability characteristics of fine-grained materials at various densities can also be determined from consolidation tests.

(a) Permeability characteristics for the design of permanent drainage systems for structures founded below the groundwater level must be obtained from laboratory tests. The tests should be performed on representative specimens of backfill materials compacted in the laboratory to densities expected in the field.

(*b*) In situ material permeability characteristics for the design of construction excavation dewatering systems can also be approximated from laboratory tests on representative undisturbed samples. Laboratory permeability tests on undisturbed samples are less expensive than in situ pumping tests performed in the field; however, laboratory tests are less accurate in predicting flow characteristics.

(6) *Slake durability of shales*. Some clay shales tend to slake when exposed to air and water and must be protected immediately after they are exposed. The extent of slaking also governs the manner in which they are treated as a backfill material (para 3-3c). Slaking characteristics can be evaluated by laboratory jar-slake tests or slake-durability tests.

(*a*) The jar-slake test is qualitative with six descriptive degrees of slaking determined from visual observation of ovendried samples soaked in tap water for as long as 24 hours. The jar-slake test is not a standardized test. One version of the jar-slake test is discussed in FHWA-RD-78-141. Six suggested values of the jar-slake index I_j, are listed below:

I_J	Behavior
1	Degrades into pile of flakes or mud
2	Breaks rapidly and forms many chips
3	Breaks rapidly and forms few chips
4	Breaks slowly and forms several fractures
5	Breaks slowly and develops few fractures
6	No change

Shales with L_J values of 1 to 3 should be protected when occurring in excavated slopes and compacted as soil if used for backfill.

(*b*) The slake-durability test is a standardized test that gives a quantitative description in percent by weight of material remaining intact at the conclusion of the test. Details of the test are presented in FHWA-RD-78-141.

(7) *Dynamic tests for special projects.* The dynamic analysis of projects subject to seismic or blast induced loading conditions requires special dynamic tests on both in situ and backfill materials. Tests required for dynamic analysis include: cyclic triaxial tests; in situ density measurements; and tests to determine shear wave velocities, shear modulus, and damping (ER 1110-2-1806).

(8) *In situ water content*. The in situ water content, including any seasonal variation, must be determined prior to construction for materials selected for use as backfill. Natural in situ water contents will determine the need for wetting or drying the backfill material before placement to obtain near optimum water contents for placement and compaction. ASTM D 2216 discusses the test method for determining water content.

3-3. Selection of backfill materials. Selection of backfill materials should be based upon the engineering properties and compaction characteristics of the materials available. The results of the field exploration and laboratory test programs should provide adequate information for this purpose. The materials may come from required excavation, adjacent borrow pits, or commercial sources. In selecting materials to be used, first consideration should be given to the maximum use of materials from required excavation. If the excavated materials are deficient in quality or quantity, other sources should be considered. Common backfill having the desired properties may be found in borrow areas convenient to the site, but it may be necessary to obtain select backfill materials having particular gradation requirements, such as filter sands and gravels and pipe or conduit bedding materials from commercial sources.

a. Primary considerations. Primary considerations for borrow material sources are suitability and quantity. Accessibility and proximity of the borrow area to the jobsite should also be considered. The water contents of the borrow area material should be determined seasonally, and a source of water should be located if the natural water contents are considerably less than the required placement water content. If several sources of suitable backfill are available, other factors to be considered in selecting the borrow materials are ease of loading and spreading and the means for adding or reducing water. The need for separating or mixing soil strata from excavation or borrow sources should be considered if necessary to provide reasonably uniform engineering properties throughout the compacted backfill.

b. Compaction characteristics. If compaction characteristics of the major portion of the backfill are relatively uniform, problems of controlling placement of backfill will be significantly reduced since the inspector will be able to develop more rapidly the ability to recognize the adequacy of the compaction procedures. In addition, the frequency of testing for compaction control could be reduced. When available backfill materials are unusual, test sections of compacted backfill are sometimes justified to develop placement procedures and to determine the engineering characteristics to be expected in field-compacted materials.

c. Workability. An important factor in choosing backfill materials is the workability or ease with which the soil can be placed and compacted. Material characteristics that effect workability include: the ease of adjusting water contents in the field by wetting or aeration; the sensitivity to the compaction water content with respect to optimum; and the amount of compaction effort required to achieve specified densities.

d. Types of backfill material. A discussion of the many types of backfill and their compaction characteristics is beyond the scope of this manual since soil types will vary on each project. However, the compaction characteristics of several rather broad categories of backfill (table 3-1) are discussed briefly. MIL STD-619 should be studied for more detailed information.

(1) Coarse-grained soils. Coarse-grained soils include gravelly and sandy soils and range from clayey sands (SC) through the well-graded gravels of gravelsand mixtues (GW) with little or no fines (table 3-1). They will exhibit slight to no plasticity. All of the wellgraded soils falling in this category have fairly good compaction characteristics and when adequately compacted provide good backfill and foundation support.

(*a*) One difficulty that might arise with soils in this category would be in obtaining good compaction of the poorly graded sands and gravels. These poorly graded materials may require saturation with downward drainage and compaction with greater compaction effort to achieve sufficiently high densities. Also, close control of water content is required where silt is present in substantial amounts. Coarse-grained materials compacted to a low relative density are susceptible upon saturation to liquefaction under dynamic loads.

(*b*) For sands and gravelly sands with little or no fines, good compaction can be achieved in either the air-dried or saturated condition. Downward drainage is required to maintain seepage forces in a downward direction if saturation is used to aid in compaction. Consideration may be given to the economy of adding cement to stabilize moist clean sands that are particularly difficult to compact in narrow confined areas.
However, the addition of cement may produce zones with greater rigidity than untreated adjacent backfill and form "hard spots" resulting in nonuniform stresses and deformations in the structure.

(*c*) Cohesionless materials are well suited for placement in confined areas adjacent to and around structures where heavy equipment is not permitted and beneath and around irregulary shaped structures, such as tunnels, culverts, utilities, and tanks. Clean, granular, well-graded materials having a maximum size of 1 inch with 95 percent passing the No. 4 sieve and 5 percent or less passing the No. 200 sieve are excellent for use in these zones. However, a danger exists of creating zones where seepage water may accumulate and saturate adjacent cohesive soils resulting in undesirable consolidation or swelling. In such cases, provisions for draining the granular backfill, sealing the surface, and draining surface water away from the structure are necessary.

(2) Fine-grained soils of low to medium plasticity. In organic clays (CL) of low to medium plasticity (gravelly, sandy, or silty clays and lean clays) and inorganic silts and very fine sands (ML) of low plasticity (silty or clayey fine sands and clayey silts) are included in this category. The inorganic clays are relatively impervious and can be compacted fairly easily with heavy compaction

equipment to provide a good stable backfill. Soils in the CL group can be compacted in confined areas to a fairly high degree of compaction with proper water content and lift thickness control. The clayey sands of the SC group and clayey silts of the ML group can be compacted to fairly high densities, but close control of water content is essential and sometimes critical, particularly on the wet side of optimum water content. Some ML soils, if compacted on the dry side of optimum, may lose considerable strength upon saturation after compaction. Considerable settlement may occur. Caution must therefore be exercised in the use of such soils as backfill, particularly below the groundwater level. Also, saturated ML soils are likely to be highly susceptible to liquefaction when dynamically loaded. Where such soils are used as backfill in seismic prone areas, laboratory tests should be conducted to determine their liquefaction potential (see para. 17-5 and 17-6, TM 5-818-1/AFM 88-3, Chap. 7).

(3) *Rock*. The suitability of rock as backfill material is highly dependent upon the gradation and hardness of the rock particles. The quantity of hard rock excavated at most subsurface structure sites is relatively small, but select cohesionless materials may be difficult to find or may be expensive. Therefore, excavated hard rock may be specified for crusher processing and used as select cohesionless material.

(4) *Shale*. Although shale is commonly referred to as rock, the tendency of some shales to breakdown under heavy compaction equipment and slake when exposed to air or water after placement warrants special consideration.

(*a*) Some soft shales break down under heavy compaction equipment causing the material to have entirely different properties after compaction than it had before compaction. This fact should be recognized before this type of material is used for backfill. Establishing the proper compaction criteria may require that the contractor construct a test fill and vary the water content, lift thickness, and number of coverages with the equipment proposed for use in the backfill operation. This type of backfill can be used only in unrestricted open zones where heavy towed or self-propelled equipment can operate.

(*b*) Some shales have a tendency to break down or slake when exposed to air. Other shales that appear rock-like when excavated will soften or slake and deteriorate upon wetting after placement as rockfill. Alternate cycles of wetting and drying increases the slaking process. The extent of material breakdown determines the manner in which it is treated as a backfill material. If the material completely degrades into constituent particles or small chips and flakes, it must be treated as a soil-like material with property characteristics similar to ML, CL, or CH materials, depending upon the intact composition of the parent material. Complete degradation can be facilitated by alternately wetting, drying, and disking the material before compaction. A detailed discussion on the treatment of shales as a fill material is given in FHWA-RD-78-141.

(5) *Marginal materials*. Marginal materials are these materials that because of either their poor compaction, consolidation, or swelling characteristics would not normally be used as backfill if sources of suitable material were available. Material considered to be marginal include fine-grained soils of high plasticity and expansive clays. The decision to use marginal materials should be based on economical and energy conservation considerations to include the cost of obtaining suitable material whether from a distant borrow area or commercial sources, possible distress repair costs caused by use of marginal material, and the extra costs involved in processing, placing, and adequately compacting marginal material.

(*a*) The fine-grained, highly plastic materials make poor backfill because of the difficulty in handling, exercising water-content control, and compacting. The water content of highly plastic finegrained soils is critical to proper compaction and is very difficult to control in the field by aeration or wetting. Furthermore, such soils are much more compressible than less-plastic and coarse-grained soils; shear strength and thus earth pressures may fluctuate between wide limits with changes in water content; and in cold climates, frost action will occur in fine-grained soils that are not properly drained. The only soil type in this category that might be considered suitable as backfill is inorganic clay (CH). Use of CH soils should be avoided in confined areas if a high degree of compaction is needed to minimize backfill settlement or to provide a high compression modulus.

(*b*) The swelling (and shrinking) characteristics of expansive clay vary with the type of clay mineral present in the soil, the percentage of that clay mineral, and the change in water content. The active clay minerals include montmorillonite, mixed-layer combinations of montmorillonite and other clay minerals, and under some conditions chlorites and vermiculites. Problems may occur from the rise of groundwater, seepage, leakage, or elimination of surface evaporation that may increase or decrease the water content of compacted soil and lead to the tendency to expand or shrink. If the swelling pressure developed is greater than the restraining pressure, heave will occur and may cause structural distress. Compaction on the wet side of optimum moisture content will produce lower magnitudes of swelling and swell pressure. Expansive clays that exhibit significant volume increases should not be used as backfill where the potential for structural damage might exist. Suitability should be based upon laboratory swell tests (TM 5-818-1/AFM 88-3, Chapter 7).

(*c*) Additives, such as hydrated lime, quicklime, and fly ash, can be mixed with some highly plastic clays to improve their engineering characteristics and permit the use of some materials that would otherwise be unacceptable. Hydrated lime can also be mixed with some expansive clays to reduce their swelling characteristics (TM 5-818-1/AFM 88-3, Chapter 7). Laboratory tests should be performed to determine the amount of the additive that should be used and the characteristics of the backfill material as a result of using the additive. Because of the complexity of soil-additive systems and the almost complete empirical nature of the current state of the art, trial mixes must be varified in the field by test fills.

(6) *Commercial by-products*. The use of commercial by-products, such as furnace slag or fly ash as backfill material, may be advantageous where such products are locally available and where suitable natural materials cannot be found. Fly ash has been used as a lightweight backfill behind a 25-foot-high wall and as an additive to highly plastic clay. The suitability of these materials will depend upon the desirable characteristics of the backfill and the engineering characteristics of the products.

3-4. Processing of backfill materials. The construction of subsurface structures often requires the construction of elements of the structure within or upon large masses of backfill. The proper functioning of these elements are often critically affected by adverse behavioral characteristics of the backfill. Behavioral characteristics are related to material type, water content during compaction, gradation, and compaction effort. While compaction effort may be easily controlled during compaction, it is difficult to control material type, water content, and gradation of the material as it is being placed in the backfill; control criteria must be established prior to placement.

a. Material type. Backfill material should consist of a homogeneous material of consistent and desirable characteristics. The field engineer must ensure that only the approved backfill material is used and that the material is uniform in nature and free of any anomalous material such as organic matter or clay pockets. Stratified material should be mixed prior to placing to obtain a uniform blend. Excavated material to be used as backfill should be stockpiled according to class or type of material.

b. Water content. While water content can be adjusted to some extent after placing (but before compacting), it is generally more advantageous to adjust the water content to optimum compaction conditions before placing. Adjustment of water content can be accomplished by aeriation (disking or turning) or sprinkling the material in 12- to 18-inch layers prior to placing or stockpiling. If the material is stockpiled, provisions should be made to maintain a constant moisture content during wet or dry seasons.

c. Ensuring gradation. Some backfill materials consisting of crushed rock, gravel, or sand require limitations on maximum and minimum particle-size or gradation distributions. Where materials cannot be located that meet gradation criteria, it may be advantageous to require processing of available material by sieving to obtain the desired gradation.